Kinematic parameters after repeated swimming efforts in higher and lower proficiency swimmers and para-swimmers.

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Abstract

Purpose: The aim of this study was to determine changes in swimming parameters, stroke coordination and symmetry after repeated high intensity swimming efforts in swimmers of different performance levels and para-swimmers. **Method:** Forty swimmers (20 able-bodied, allocated to higher and lower performance groups- G1 and G2, respectively – and 20 impaired swimmers – S5 to S10) were recorded by 4 underwater cameras while performing repeated 50m maximum front-crawl swimming with a ten-second interval for each time endured by the swimmer. A cycle stroke was digitized using SIMI Reality Motion Systems in the first and last trials to analyze the kinematic parameters. The comparison among groups and conditions was performed by Mixed ANOVA Models with $p<0.05$. **Results:** For all groups, swimming velocity, stroke rate and stroke index showed reduction over time, while stroke length and intracyclic velocity variation did not show significant changes. **Conclusions:** Training to maintain stroke rate is necessary to support performance since it is the main cause of velocity decrease. Stroke dimensions and individual underwater phases were not sufficient to distinguish groups or conditions. Hand velocity decreased probably due to a decline in energy capacity, propulsive force and passive drag caused by the fatigue process.

Key-words: performance, fatigue, biomechanics, aquatic sport

Introduction

Sustaining swimming performance at high intensity has been associated with movement pattern changes and has been widely studied due to analogies regarding the damaging effects of fatigue on performance (Morgan Alberty, Sidney, Pelayo, & Toussaint, 2009; Figueiredo, Sanders, Gorski, Vilas-Boas, & Fernandes, 2013; Kennedy, Tamminen, & Holt, 2013). These effects seem to be more evident from the second half and the end of the race. Indeed, some studies have reported velocity reductions from 6.0 to 12.4% in a 100m race (Chollet, Delaplace, Pelayo, Tourny, & Sidney, 1997; Pai, Hay, & Wilson, 1984; Toussaint, Carol, Kranenborg, & Truijens, 2006). The differences between studies can be explained by the skill level, since the most proficient swimmers have better capacity to maintain velocity (Craig, Skehan, Pawelczyk, & Boomer, 1985). Decrease in stroke length has also been described when swimmers of mid- and low-performances were compared. It seems that elite swimmers are able to sustain greater stability in the stroke length throughout the race (Ludovic Seifert, Chollet, & Chatard, 2007). The trajectory and stroke parameters of most proficient swimmers seem to be fairly resistant to changes even in the final stages of the trials, when fatigue processes are likely to influence performance more pronouncedly (Matthews, Green, Matthews, & Swanwick, 2017).

Changes in the stroke length and stroke rate have been associated with attempts to maintain swimming velocity (M Alberty, Sidney, Huot-Marchand, Hespel, & Pelayo, 2005; Stelios Psycharakis and Sanders, 2008). Thus, comparable velocity can be obtained with different combinations of stroke length and stroke rate (Arellano and Brown, 1994; Hellard et al., 2008; Pai, et al., 1984). One of the most frequent strategies to maintain swimming velocity is to increase the stroke rate in order to compensate the decrease stroke length (Morgan Alberty et al., 2008). However, the stroke rate, stroke length and swimming velocity tend to decrease as the race unfolds(Stirn, Jarm, Kapus, & Strojnik, 2011).

Sustaining high-intensity efforts may cause stroke coordination changes in order to sustain the external output (swimming velocity) in response to the diminished ability of the muscles to generate force/power. Reductions in the relative duration of the non-propulsive stroke phase (recovery phase) have been observed as a strategy to increase the relative duration of the propulsive phase in an attempt to increase momentum. Therefore, the relative duration in the stroke phase may allow a better understanding of how swimmers organize swimming actions during high-intensity efforts (Morgan Alberty, et al., 2009). Adjustment in swimming parameters are also influenced by race distance (Figueiredo, et al., 2013; Komar et al., 2012; Toussaint, et al., 2006) and proficiency level of the swimmers (Chollet, et al., 1997; Santos, Lara, & Rodacki, 2017).

Changes in performance may be more evident in swimmers with physical disabilities, since performance level depends on their functional classification (Fulton, Pyne, Hopkins, & Burkett, 2009; Wu and Williams, 1999). It is expected that performance is closely related to their ability to exert maximum efforts (Dingley, Pyne, & Burkett, 2014). In addition, these responses may occur early or according to the severity of the disability. For example, Lee and colleagues (Lee, Sanders, & Payton, 2014) observed a 20% lower force production in unilateral arm-amputee para-swimmers in comparison to able-bodied swimmers. Therefore, more pronounced declines in stroke frequency were also found, although the fatigue rate was comparable among groups. Stroke rate declines were also reported, although the fatigue index (i.e., decline in force production over a given time period) was comparable between groups.

These studies demonstrate swimming parameters change as a function of a specific distance race, however, they may not represent changes when the stimuli are gradually increased (Matthews, et al., 2017). These changes may present marked results in response to increasing demand. Studies that induce greater stimuli are necessary to verify if the demands make adaptations in swimming characteristics more evident. In an overview, para-swimmers investigations have gained attention in recent years due to the growth of participants in sports and the results achieved in major competitions such as the Paralympic Games. These improved performances have been possible due to advances in specific training methods. However, to our knowledge, the sustained impact of high-intensity swimming repetitions on dimensional parameters, stroke coordination, and stroke symmetry of para-swimmers has not been established. This information may allow coaches and swimmers to develop new strategies to keep swimming parameters more stable during a race. In addition, objective information that allows the review of criteria used for the classification between para-swimmers can be obtained. In fact, the classification system has been performed subjectively and experimental analyzes can contribute to more objective measures. Such measures may consider how the disability limits performance and affects the swimmer's ability to sustain it.

The aim of this study was to determine changes in swimming parameters, stroke coordination and symmetry after repetitive high intensity swimming efforts in swimmers of different performance levels and para-swimmers. It was hypothesized that velocity, stroke rate, stroke length and time spent in the recovery phase would decrease during the repetitions. On the other hand, time spent in the underwater phase, asymmetry of dimensional parameters of the stroke and coordination would increase. In addition, it was assumed that there were more pronounced alterations, firstly in the para-swimmers, then in the swimmers with a lower technical index, and finally, more tenuous, in the swimmers of greater proficiency.

Method

Participants

The present study consisted of 20 able-bodied swimmers (18.45 ± 3.78 years, 1.72 ± 0.10 m and 66.35 ± 10.33 kg) and 20 para-swimmers with physical-motor disabilities (19.19 ± 2.82 years, 1.67 ± 0.09m, 58.89 ± 11.46kg). The inclusion criteria were: (i) sprint specialist swimmers, (ii) at least 15 years old, (iii) minimum three-year competitive experience, (iv) regular training session frequency equal to or higher than 5 times per week. The para-swimmers should have been previously classified according to IPC between S5 to S10 classes. Impairments included amputation at the elbow level, cerebral palsy, myelomeningocele, brachial plexus paralysis, arthrogryposis, double leg amputation at knee level, congenital malformation, dwarfism and spina bifida.

The able-bodied participants were allocated to a higher performance group (G1 - 10 swimmers) and lower performance group (G2 - 10 swimmers), determined by the score proposed by the International Swimming Federation:

$$P = 1000\left(\frac{B}{T}\right)^3$$

where P refers to the points (score), B to the base time (based on world record) and T to the time obtained by the swimmers. The average score of the highly proficient swimmers was of 612 ± 93 points, while the swimmers with lower proficiency scored 427 ± 66 points. Participants and/or parents or guardians provided an informed consent form. The data collection procedures were approved by the Institutional Ethics Committee.

Instruments and procedures

Swimmers were invited to participate in a single experiment session held in a 25m swimming pool (~ 28 ° C). Measurements in a set of anthropometric measures (weight, height and arm span) preceded the experimental procedure. After 600m of uncontrolled warm-up, swimmers were instructed to execute a repeated maximum performance of 50m front crawl swimming with a ten-second interval for each time endured by the swimmer. The lowest number of repetitions was 6 and the highest one was 12, with a mean of 7 ± 2 trials between able-bodied swimmers and 8 ± 2 trials for the physically disabled. In addition, a follow-up of the velocity reduction between each trial was performed and the last 50m occurred with a minimum of 10% velocity reduction compared to the first 50m.

Swimmers were asked not to breathe when they passed through the calibrated area to inhibit possible breathing influences on the motor gesture. The start was performed from inside the pool and the participants received verbal encouragement during the test.

Swimmers were recorded by 4 underwater cameras. The cameras were synchronized by a light pulse positioned in the visual field of all cameras. The underwater cameras used with Brazilian swimmers were GoPro Hero 4 with frequency of acquisition at 60 Hz, while British para-swimmers were filmed by Mako G-223B from Allied Visions Technology placed in underwater housings from Autovimation Nautilus (IP 68 rated) with a frequency of 50 Hz. Two cameras were positioned diagonally on the right side of the swimmer and two on the left side with approximate angles of 90° between each other. Each camera focused on a volume previously calibrated in the pool with the measures of 3.5m length (x), 1.0m wide (y) and 1.5m deep (z), with 54 underwater control points.

The markers were positioned in both sides of the swimmers in the anatomical points: distal phalanx of the 3rd metacarpal and major trochanter of the femur. The markers were digitized in a specific kinematic analysis software (SIMI Reality Motion Systems) and the measurements proved to be highly reproducible and replicable (ICC 0.99) (Santos, et al., 2017). The two-dimensional coordinates were filtered at 7Hz using a low-pass Butterworth filter (2nd order). Then they were converted into three-dimensional coordinates using a direct linear transformation (DLT) algorithm (Silvatti et al., 2013).

A complete stroke cycle was analyzed, defined by the entry of one hand into the water until the next entrance of the same hand. The cycle was divided in four phases adapted from Payton and coworkers (Payton, Bartlett, Baltzopoulos, & Coombs, 1999):

1. Glide + Downsweep: from the entry to the most lateral position of the hand.

2. Insweep: from the end of the downsweep to the most medial position of the hand.

3. Upsweep: from the end of the insweep to hand exit.

4. Recovery: from the end of the upsweep to next hand entry.

The first three phases correspond to the underwater stroke.

The following parameters were analyzed:

• Swimming velocity (Vel): the product between stroke rate and stroke length.

• Stroke length (SL): distance covered by the body during a stroke cycle.

• Stroke rate (SR): calculated by extrapolating the number of cycles per minute, by the time spent to perform a single stroke.

• Stroke index (SI): the product between velocity and stroke length.

• Intracyclic velocity variation (IVV): estimated by the variation coefficient of the hip progression rate (ratio between the standard deviation of the hip displacement mean velocity on the x-axis, and the mean hip velocity on the same axis during a stroke cycle)

• Stroke width: displacement of the y-axis by the difference between the most lateral and medial position.

• Stroke depth: displacement of the z-axis between the entry of the hand in the water to the deepest point.

• Underwater stroke amplitude: displacement of the x-axis by the difference between input and output of the hand in the underwater phase.

• Percentage of time in the underwater phase: percentage time spent between hand input and output in the water in relation to the total stroke cycle time.

• Percentage of time in the recovery phase: percentage time spent between hand output and input in the water in relation to the total stroke cycle time.

• Index of Coordination (IdC): adapted from Chollet et al. (2000), considering the percentage of stroke opposition (IdC = 0), time lapse (IdC <) or overlap of arms (IdC> 1) in the propulsive phase (insweep + upsweep).

• Mean velocity of the hand in the underwater phase: ratio between the trajectory resulting from the underwater phase and the time spent to complete this phase.

• Mean velocity of the hand in each underwater stroke phase: ratio between the trajectory in each underwater phase (downsweep, insweep and upsweep) and the time spent to complete each phase.

Only the first and last series were recorded and analyzed. Comparisons were made between initial and final protocol conditions and between groups of higher and lower proficiency.

Statistical analyses

The normality of the variables was tested by the Shapiro-Wilk test and homogeneity by the Levene test. The comparison between groups in initial and final conditions, for dominant and non-dominant sides was performed by Mixed ANOVA Models. The effect size (d) was calculated considering the ratio between the mean of the conditions (initial and final) and their standard deviations (Thalheimer and Cook, 2002). According to Cohen, effect size greater or equal to 0.80 represents a large change, between 0.5 and 0.8

- moderate change and effect size lower or equal to 0.20 - small change. Statistical analysis was performed using a specific software (Statistic, version 7, Statsoft) with significance level adopted at $p < 0.05$.

Results

Swimming parameters at the start and end of the test were showed in order to identify the changes occurred. In sequence, unilateral variables of dominant and non-dominant arms are presented to analyze the changes occurring in each hemibody. The initial and final conditions for swimming parameters in the 3 groups of swimmers are represented in table 1. Swimmers of higher performance were the fastest. Able-body swimmers showed higher stroke length and swimming index than para-swimmers, while stroke rate and intracyclic velocity variation did not differ between groups.

TABLE 1 ABOUT HERE

Swimming velocity, stroke rate and stroke index showed reduction of approximately 18%, 19% and 16% respectively, with a moderate to high effect size in the different groups ($p<0.01$ – Table 1). The stroke length and intracyclic velocity variation did not show significant changes over time. The results regarding stroke dimension, index of coordination and stroke phases in both hemibodies, in the three groups of swimmers are presented in the table 2. Stroke dimensions and individual underwater phases did not differ between initial and final condition, arm dominance or level of swimmers proficiency (except for an increase in the medial-lateral amplitude for the dominant arm in the para-swimmer group). Nevertheless, the index of coordination increased in all groups for the dominant arm, while the velocity decreases in each underwater phase.

TABLE 2 ABOUT HERE

Discussion

This study compared swimming parameters, stroke dimensions, coordination between stroke phases and their symmetry before and after swimming efforts at high intensity in swimmers of different proficiency levels and para-swimmers.

The reduction of velocity and the stroke index after maximum repetitions efforts in the groups indicates a decrease in performance and suggests the establishment of fatigue process. Chollet et al. (1997) reported reductions of 5.7% in swimming velocity in the second half of a 100m test, while, Pai et al. (1984) reported decreases of 6.3% and Toussant et al. (2006) of 12.4%. These studies demonstrate swimming parameters change in a short period of time, which may differ from those that occur when higher efforts are sustained (Matthews, et al., 2017). Increased demands on effort may generate more evident changes in swimming characteristics. In fact, our results point to a more expressive reduction of velocities with a protocol of 50m maximum repetitions until self-reported inability to continue the test.

Higher level swimmers had a greater reduction in velocity (20.9%) than the other groups (17.4% and 13.0%). The hypothesis that more proficient swimmers would show less reduction in swimming velocity was not confirmed. A possible explanation is that the less proficient swimmers and para-swimmers did not perform their maximum velocity in the first trial in order to protect themselves for the subsequent trials. In fact, the most proficient swimmers presented higher initial velocities (thus, a larger "window" of change) and performed fewer repetitions in relation to the para-swimmers (6 vs. 8 repetitions). The velocity reduction observed in able-bodied swimmers is in accordance with the results reported by Seifert et al. (2007) in a 100m race. The literature review indicates a discrepancy in findings, which can be explained by the different methodologies used. For example, Chollet et al. (1997) and Pai et al. (1984) found a reduction of approximately 6% versus 20% reported by Seifert et al. (2007). Some of these studies evaluate changes between two halves of the test (15 versus 65m), while others divide footage into 4 partial to make comparisons between quartiles. Likewise, the pacing strategy used by swimmers may also interfere with the results. The present study compared an arm stroke cycle in the first half of the test in different trials of 50 meters, which decreases the influence of pacing strategy adoption usually performed in long distance swimming.

The shortest stroke length of the para-swimmers can be explained by the limitations imposed by the physical disability (arm amputation, dwarfism, inability to extend the arm, low flexibility, etc.). The general maintenance of the stroke length during the tests can be attributed to the refinement of the technical execution, since excellent swimmers tend to show smaller changes in the stroke parameters, even when exposed to the effects of fatigue (Matthews, et al., 2017). On the other hand, the stroke rate decrease corroborates with finds previously reported (Tella et al., 2008; Weiss, Reischle, Bouws, Simon, & Weicker, 1988) and may be due to the high demand of efforts imposed. In contrast, some studies report increases in stroke rate over time (Morgan Alberty, et al., 2008; Komar, et al., 2012; Stelios Psycharakis and Sanders, 2008). It seems that there is a tendency to increase stroke rate in an attempt to maintain velocity, but with repeated efforts, both stroke rate and swim velocity decrease (Stirn, et al., 2011). The hypothesis that the swimming parameters (Vel, SL, SR and SI) would decrease at the end of the test was partially confirmed, since the stroke length was maintained, while the other variables decreased. The hypothesis that the changes would be less pronounced in the higher proficiency group was rejected, since there was no difference between groups regarding changes from the beginning to the end of the test. Parameters of velocity, stroke length and stroke index distinguished the groups of swimmers with and without physical-motor disabilities and the level of performance.

The intracyclic velocity variation was not altered at the end of the test and corroborates with previous studies (Figueiredo, Barbosa, Vilas-Boas, & Fernandes, 2012; SG Psycharakis, Naemi, Connaboy, McCabe, & Sanders, 2010). The hypothesis that lower performance swimmers and para-swimmers would show greater intracyclic velocity variation was not confirmed. This can be explained because the front crawl is considered the most economical swimming style, with alternating propulsive phases, which generates smaller and more stable intracyclic velocity variation. In addition, perhaps the technical adaptations of the swimmers (and para-swimmers) during the test (for example, the increase of the index coordination), allowed intracyclic velocity variation maintenance even after sustaining repeated swimming efforts. Intracyclic velocity variation does not appear to be capable of predicting performance, since it did not differ between groups or conditions.

Stroke dimension (underwater width, depth and amplitude) did not change at the end of maximum efforts, except for an increase in the medial-lateral amplitude for the dominant arm in the para-swimmer group. Perhaps sustaining maximum efforts has a greater influence on other aspects of the stroke than on its dimensional characteristics. Such aspects may comprise a robust pattern of consistent response over performance as a function of its long practice, regardless of the velocity performance. In fact, at the time of the testing all the swimmers evaluated are experienced, used to training at least 5 times per week and used to practicing swimming under high-intensity conditions. This may have influenced the ability to maintain the dimensional aspects of the stroke until the end of the test.

The increase in the percentage of time spent in the underwater phase (and consequent reduction of the recovery phase) for lower performance swimmers may have occurred due to reductions in hand velocity during the underwater phase. The highest proficiency group decreased the percentage of time spent in the recovery phase for the non-dominant arm, which corroborated with previous results in the literature (Morgan Alberty, et al., 2008; Santos, et al., 2017; L Seifert, Chollet, & Allard, 2005). Hand velocity decrease in the underwater phase has been indicated as responsible for the observed adaptations. The similarity between groups for the percentage of time spent in the above and underwater phases indicates that the temporal structure of the stroke phases is similar in swimmers, regardless of the level of performance. This organization seems to consist a stereotyped aspect of the modality.

Index of coordination increased in all groups for the dominant arm. The increase in stroke overlap at the end may correspond to a strategy used in the attempt to maintain the velocity (Morgan Alberty, et al., 2009). Seifert et al. (2007) observed that less proficient swimmers modify the index of coordination from an oppositional model to overlap in a fatigue condition. However, this artifice may not be effective, since the stroke length and velocity continued to decrease as the effort was repeated (fatigue). In the present study, the increase in the index of coordination for the dominant arm occurred without changing the stroke length, however, the hand velocity and the stroke rate decreased. This suggests that increases in the proportion of time spent in the propulsive phase and stroke overlap are not sufficient to maintain swimming velocity during the performance of high intensity efforts. Interestingly, the same behavior was not observed for the non-dominant arm. Perhaps the strategy of support and propulsive force application between arms explain this difference. Indeed, Seifer et al. (2005) and Formosa et al. (2013) attributed the difference to the functional role of each stroke, i.e. the dominant segment is more responsible for the production of higher forces, while the non-dominant one assumes actions more related to control and support. The non-dominant arm of the para-swimmers had the longest time of arm-stroke propulsion (capture model) and may be related to the lower performance of the group, since lower index of coordination are associated with the lower performances (Formosa, Sayers, & Burkett, 2013). The more proficient swimmers showed a lower index of coordination at the beginning for the dominant arm and as the protocol progressed, it was increased. The increase in the index of coordination may have occurred in order to apply more evenly the propulsive force in each stroke. Thus, the difference in the percentage of overlapping strokes was reduced at the end of the protocol.

The percentage of time spent in each underwater stroke phase (i.e, downsweep, insweep and upsweep) did not show any difference between conditions or dominance of arms in all groups. It appears that the temporal structure of the underwater stroke phases, when analyzed individually, is not easily modifiable and is not sufficient to distinguish dominance, performance level and group of swimmers from para-swimmers.

Hand velocity decrease in each underwater phase and suggests the establishment of a fatigue process. Similarly, the velocity of the hand may have interfered in swimming velocity, since the hand is assumed to be the main propulsive force generator (Suito et al., 2008). Therefore, swimmers' exhaustion at the end of the test may have reduced propulsive efficiency and resulted in lower swimming velocity (Toussaint, et al., 2006). In addition, the resistive forces may also have been increased due to a body misalignment as a result of fatigue process and contributed even more to the reduction of the hand velocity and consequently swimming velocity. Therefore, the hypothesis that the hand velocity would reduce as a function of time, with more pronounced changes in the para-swimmers, then in the swimmers with a lower technical index and, finally, in the swimmers of greater proficiency was partially accepted. The lower stroke efficiency in lower level swimmers may explain the slower swimming velocity even with similar hand velocity. In fact, stroke efficiency results from the ratio of swimming velocity to mean hand velocity (Figueiredo, Zamparo, Sousa, Vilas-Boas, & Fernandes, 2011). The body misalignment and greater passive drag faced by these swimmers may have contributed to this result (Cappaert, Pease, & Troup, 1995; Oh, 2015), as well as possible inadequacy of the propulsive force angle application of the hand during the swimming (Schleihauf et al., 1988).

Limitations

Differences in the data collection system and sampling rates may have affected the comparisons. Although errors from 3D analysis are deemed as low, sampling frequency differences of 10Hz may have introduced small differences. Further studies comparing different settings and including a larger number of swimmers with different disability levels are encouraged.

What does this article add?

The results presented may allow coaches to have new ideas on how to keep swimming parameters more stable during a race. Due to the importance of the stroke length to improve performance, it would be beneficial for swimmers to train to increase their amplitude and maintain it during high stimuli efforts. However, the reduction in stroke rate was the main cause of performance decrease, since velocity is determined by the product between the stroke length and its rate and only the stroke rate changed at the end of the test. Thus, training to maintain stroke rate is necessary when performance sustaining is required.

Stroke dimensions and individual underwater phases were not sufficient to distinguish initial and final conditions, arm dominance and level of proficiency of the swimmers. On the other hand, when considering the underwater phases as a whole, swimmers demonstrated coordination adaptation of the stroke during the protocol with an increase in the underwater time and overlap of the arm in the propulsive phase for dominant segment. In addition, hand velocity decreased probably due to a decline in energy capacity, propulsive force and passive drag caused by the fatigue process.

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Table 1 - Swimming parameters comparison between initial (Ini) and final (Fin) conditions for swimmers of higher (G1), lower (G2) performance and para-swimmers (G3).

	G1 (10)		**d**	**G2 (10)**		**d**	**G3 (20)**		**d**	**p (Ini-Fin)**	**p (Inter)**
	Ini	Fin		Ini	Fin		Ini	Fin			
Vel	1.63	1.29[a]	0.76	1.38[b]	1.14[a]	0.50	1.15[bc]	1.00[ab]	0.16	0.00	0.01
	(0.15)	(0.15)		(0.17)	(0.15)		(0.23)	(0.28)			
SL	2.00	2.05	0.07	1.78	1.88	0.10	1.45[bc]	1.43 [bc]	0.02	0.80	0.13
	(0.19)	(0.27)		(0.29)	(0.37)		(0.25)	(0.26)			
SR	48.88	37.81[a]	0.95	47.26	37.24[a]	0.58	47.61	41.93[a]	0.20	0.00	0.04
	(3.61)	(4.16)		(4.82)	(6.53)		(6.92)	(8.80)			
SI	3.26	2.64 [a]	0.61	2.45	2.14	0.40	1.67[bc]	1.43[abc]	0.50	0.00	0.02
	0.28	0.3		0.27	0.22		0.18	0.12			
IVV	0.21	0.22	0.04	0.22	0.22	0.00	0.24	0.26	0.05	0.65	0.87
	(0.08)	(0.08)		(0.09)	(0.10)		(0.09)	(0.12)			

Vel – swimming velocity; SL – stroke length; SR – stroke rate; SI – stroke index; IVV – intracyclic velocity variation. Inter – interaction. [a] difference between initial and final conditions; [b] different from group 1; [c] different from group 2

Table 2 – Stroke dimensions, index of coordination and stroke phases comparison between dominant (D) and not dominant (ND) side, initial (ini) and final (fin) conditions for swimmers of greater (G1), lower (G2) performance and Para-swimmers (G3).

	Initial Condition						Final Condition								
	G1 (10)		G2 (10)		G3 (20)		G1 (10)		G2(10)		G3 (20)		p (ini-fin)	*d* (ini-fin)	p (Inter)
	D	ND	D	ND	D	ND	D	ND	D	ND	D	ND			
Amplitude (m)	0.70	0.70	0.69	0.69	0.68	0.70	0.78	0.81	0.78	0.79	0.70	0.74	0.05	0.46	0.97
	(0.16)	(0.09)	(0.13)	(0.10)	(0.10)	(0.12)	(0.15)	(0.23)	(0.27)	(0.25)	(0.17)	(0.11)			
Width (m)	0.36	0.25[a]	0.28	0.30	0.27	0.32	0.37	0.27[a]	0.32	0.28	0.31[b]	0.31	0.13	0.15	0.40
	(0.12)	(0.09)	(0.08)	(0.12)	(0.09)	(0.08)	(0.13)	(0.09)	(0.08)	(0.07)	(0.09)	(0.07)			
Depth (m)	0.70	0.70	0.62	0.64	0.62	0.57[c]	0.69	0.69	0.62	0.67	0.58[c]	0.62[a]	0.95	0.04	0.03
	(0.06)	(0.07)	(0.09)	(0.09)	(0.11)	(0.13)	(0.09)	(0.09)	(0.08)	(0.08)	(0.13)	(0.11)			
Underwater time (%)	68.49	68.64	69.99	69.80	69.50	69.06	70.59	73.23[b]	76.02[b]	74.46[b]	69.60	72.21[a]	0.00	0.65	0.46
	(4.92)	(4.62)	(4.10)	(4.54)	(5.16)	(6.55)	(6.57)	(5.19)	(3.48)	(6.27)	(6.34)	(6.22)			
Recovery time (%)	31.51	31.36	30.01	30.20	30.50	30.94	29.41	26.77[b]	23.9 [b]	25.54	28.40	27.79[b]	0.00	0.72	0.46
	(4.92)	(4.62)	(4.10)	(4.54)	(5.16)	(6.55)	(6.57)	(5.19)	(3.48)	(6.27)	(6.34)	(6.22)			
IdC (%)	0.10	2.9[a]	-0.3	0.3	-1.80	-4.25[acd]	2.30[b]	3.1	2.3[b]	-1.5[a]	0.00[bd]	-4.53[acd]	0.01	0.15	0.01
	(4.32)	(3.21)	(5.21)	(4.96)	(5.29)	(5.21)	(7.98)	(6.79)	(6.65)	(3.17)	(4.39)	(7.11)			
Donwsweep (%)	19.32	19.52	19.86	20.79	25.63	27.53	20.72	22.34	26.26	29.06	26.86	28.79	0.15	0.24	0.90
	(15.83)	(12.14)	(13.44)	(16.16)	(12.50)	(13.29)	(14.69)	(16.76)	(18.45)	(18.69)	(12.53)	(12.70)			
Insweep (%)	30.48	26.88	24.96	23.32	22.73	22.89	30.01	28.78	26.29	22.83	23.96	23.98	0.40	0.07	0.85
	(12.27)	(8.53)	(10.74)	(9.81)	(6.74)	(8.39)	(15.27)	(14.79)	(16.27)	(11.29)	(9.66)	(10.14)			
Upsweep (%)	18.82	22.25	25.17	25.68	21.72	18.65	20.83	22.11	23.47	22.57	20.78	19.44	0.24	0.07	0.90
	(9.44)	(9.42)	(6.75)	(7.02)	(8.06)	(8.51)	(9.76)	(7.20)	(5.32)	(9.04)	(8.81)	(6.53)			
Vel Downsweep ($m.s^{-1}$)	2.06	1.95	1.76	1.66	1.79	1.77	1.70[b]	1.71[b]	1.47[b]	1.48	1.50[b]	1.57[b]	0.00	0.82	0.98
	(0.37)	(0.20)	(0.27)	(0.36)	(0.28)	(0.47)	(0.19)	(0.39)	(0.23)	(0.39)	(0.36)	(0.33)			
Vel insweep ($m.s^{-1}$)	2.36	2.25	1.99	2.02	2.18	2.14	1.87[b]	1.82[b]	1.58[b]	1.49[b]	1.91[b]	1.99	0.00	1.13	0.89
	(0.32)	(0.32)	(0.31)	(0.24)	(0.54)	(0.43)	(0.26)	(0.34)	(0.24)	(0.19)	(0.52)	(0.37)			
Vel upsweep ($m.s^{-1}$)	2.72	2.52	2.51	2.32	2.43	2.67[ad]	2.37	2.33	2.20	1.76[b]	2.23	2.43[b]	0.00	0.89	0.71
	(0.34)	(0.22)	(0.47)	(0.29)	(0.43)	(0.35)	(0.21)	(0.23)	(0.24)	(0.44)	(0.54)	(0.47)			
Vel underwater ($m.s^{-1}$)	2.36	2.25	2.10	2.05	2.13	2.17	1.99[b]	1.9[b]	1.73[b]	1.90[b]	1.85[b]	1.92[b]	0.00	1.26	0.99
	(0.30)	(0.21)	(0.26)	(0.17)	(0.23)	(0.30)	(0.19)	(0.16)	(0.19)	(0.16)	(0.40)	(0.27)			

IdC - Index of coordination; Vel – Velocity. Inter – Interaction. [a] - difference between sides; [b] - difference between initial and final conditions; [c] - different from group 1; [d] - different from group 2.